Normative Deliberation in Graded BDI Agents

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Open MAS

Open Multi-Agent Systems

- Heterogeneity of their participants
- Limited trust
- Possible individual goals in conflict and
- High **Uncertainty**
  - Limited knowledge of the word
  - The environment is opaquely perceived

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Norm and Normative Aware Agents

Norms

- Ensuring social order
- Avoiding conflicts

Normative agents

Have explicit knowledge about norms

- Able to **acquire** new norms
- **Deliberate** about norm compliance autonomously

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Proposal

Extend the Multi-Context Graded BDI agent architecture:

- Allow agents to **acquire** norms
- **Consider** them in their decision making processes

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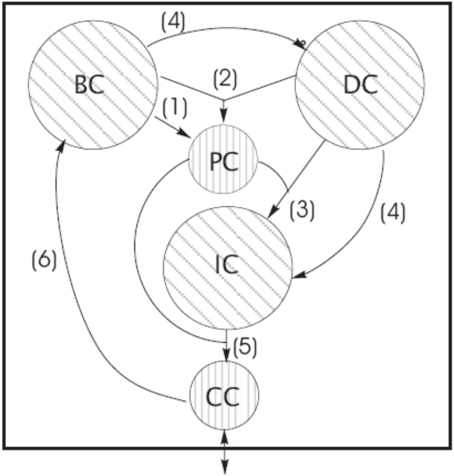
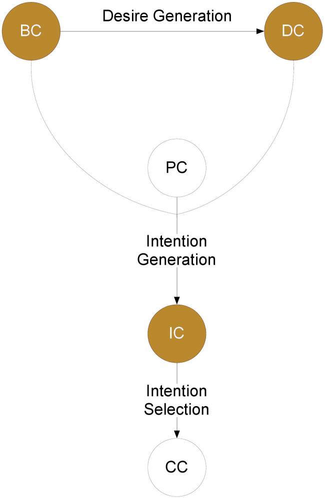
Multi-Context Graded BDI Architecture[1]



[1] A. Casali. *On Intentional and Social Agents with Graded Attitudes*

Mental Contexts



- *Belief Context (BC)*

$$(B\gamma, \beta_\gamma)$$

- *Intention Context (IC)*

$$(I\gamma, \iota_\gamma)$$

- *Desire Context (DC)*

$$(D^*\gamma, \delta^*_\gamma)$$

  - $* \in \{+, -\}$ positive and negative desires

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m-Water Case-Study: Mental Propositions

In the m-Water scenario, the *irrigator* agent represents a farmer who wants to pick up high quality vegetables:

$$(D^+ highQuality, 1)$$

He has two different irrigation possibilities:

$$(B\ [fullIrrigation] highQuality, 0{,}75)$$

$$(B\ [halfIrrigation] highQuality, 0{,}5)$$

He beliefs that there is a rather possibility of drought:

$$(B\ drought, 0{,}6)$$

He also does not desire to be fined:

$$(D^- payFine, 0{,}8)$$

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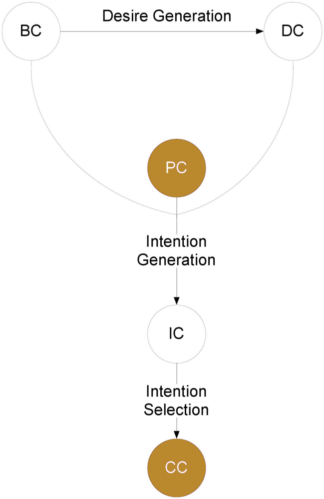
Functional Contexts



- *Planner Context (PC).* It allows agents to determine sequence of actions that will be intended according to their desires.
- *Communication Context (CC).* It communicates agents with their environment

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m-Water Case-Study: Plans

The *irrigator* has two different cultivation plans:

$$plan(fullIrrigation)$$

$$plan(halfIrrigation)$$

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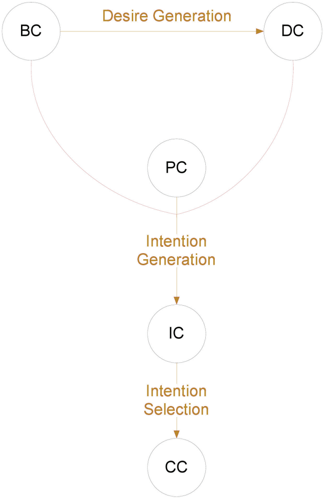
Bridge Rules



- *Desire Generation*

$$\frac{DC : (D^{*}\varphi, \delta^{*}_{\varphi}), BC : (B([\alpha]\varphi), \beta_{\phi})}{DC : (D^{*}[\alpha]\varphi, f_D(\delta^{*}_{\varphi}, \beta_{\phi}))}$$

- *Intention Generation*

$$\frac{DC : (D^{+}[\alpha]\varphi, \delta^{+}_{[\alpha]\varphi}), DC : (D^{+}\alpha, \delta^{+}_{\alpha}), PC : plan(\Sigma), \alpha \in \Sigma \quad \ldots, DC : (D^{-}[\alpha]\psi_i \delta^{-}_{[\alpha]\psi_i}), \ldots, \delta^{+}_{[\alpha]\varphi} + \delta^{+}_{\alpha}) \geq \sum_{k=1}^{n} \delta^{-}_{[\alpha]\psi_k}}{IC : (I[\alpha]\varphi, f_I(\delta^{+}_{[\alpha]\varphi} + \delta^{+}_{\alpha}, \sum_{k=1}^{n} \delta^{-}_{[\alpha]\psi_k}))}$$

- *Intention Selection* :

$$\frac{IC : (I[\alpha]\varphi, \iota_{max})}{CC : act(\alpha)}$$

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m-Water Case-Study: Desire Generation

In the case of the *irrigator* agent, he refines his abstract desires into more realistic ones according to his beliefs:

$$\frac{DC : (D^+ \ highQuality, 1), BC : (B \ [fullIrrigation]highQuality, 0{,}75)}{DC : (D^+ \ [fullIrrigation]highQuality, 0{,}75)}$$

$$\frac{DC : (D^+ \ highQuality, 1), BC : (B \ [halfIrrigation]highQuality, 0{,}5)}{DC : (D^+ \ [halfIrrigation]highQuality, 0{,}5)}$$

m-Water Case-Study: Intention Generation

In the m-Water scenario, the derived specific desires allow the *irrigator* agent to determine which actions will be intended according to the existing plans:

$$\frac{DC : (D^{+}\,[fullIrrigation]highQuality, 0{,}75), PC : plan(fullIrrigation), 0{,}75 > 0}{IC : (I[fullIrrigation]highQuality, 0{,}75)}$$

$$\frac{DC : (D^{+}\,[halfIrrigation]highQuality, 0{,}5), PC : plan(halfIrrigation), 0{,}5 > 0}{IC : (I[halfIrrigation]highQuality, 0{,}5)}$$

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m-Water Case-Study: Intention Selection

In the m-Water scenario, the *irrigator* agent will perform the most intended action:

$$\frac{IC : (I[fullIrrigation]highQuality, 0{,}75)}{CC : (act(fullIrrigation))}$$

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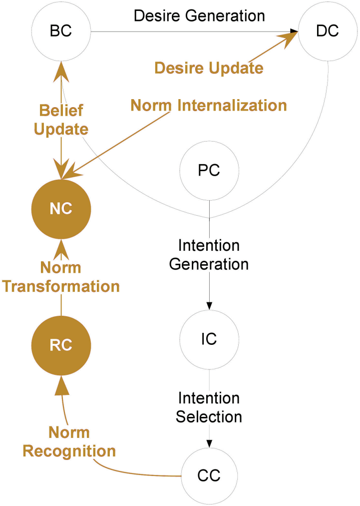
Normative BDI Architecture



Two new functional contexts are defined:

- *Recognition Context* (RC) responsible for the norm acquisition
- *Normative Context* (NC) allows agents to consider norms in their decisions

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Recognition Context (RC)

Recognition Context (RC)

Formed by expressions defined as $(RC\ n, \rho_n)$:

- n is a norm:

Definition (Norm)

A norm n is defined as $n = \langle D, C, A, E, S, R \rangle$ where:

- $D \in \{O, F\}$, is the deontic modality
- C normative condition
- A, E norm activation and expiration conditions
- S, R sanctions and rewards

- $\rho_n \in [0, 1]$ is the certainty degree ascribed to the recognised norm

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m-Water Case-Study: Irrigation Norms

In the m-Water scenario, it is forbidden to irrigate all their cultivation if a drought state has been declared in this area, so any agent which violates this norm will be sanctioned by paying a fine:

$$(RC\ \langle Prohibition, drought, -, fullIrrigation, payFine, -\rangle, 1)$$

Normative Context (NC)

Normative Context (NC)

The NC is formed by expressions like $NC(\lceil\gamma\rceil)$; where γ relates mental attitudes of an agent:

$$
\begin{aligned}
\gamma &:= \varphi \rightarrow \psi \\
\varphi &:= \psi \mid \psi \wedge \varphi \\
\psi &:= \phi \mid \neg\phi \\
\phi &:= (B\,\alpha, \delta) \mid (D^{+}\,\alpha, \delta) \mid (D^{-}\,\alpha, \delta)
\end{aligned}
$$

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Norm Transformation Bridge Rules: Obligation Transformation Rule

$$\frac{RC : (RC\ \langle O, A, E, C, S, R\rangle, \delta_{nr})}{\begin{array}{c} NC : \lceil (B\ A, \delta_A) \wedge (B\neg E, \delta_E) \wedge (D^+ C, \delta_C) \wedge (D^- S, \delta_S) \wedge (D^+ R, \delta_R) \\ \rightarrow \\ (D^+ C, f(f_{compliance}(\delta_C, \delta_S, \delta_R), f_{activation}(\delta_A, \delta_E, \delta_{nr})))\rceil \end{array}}$$

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Norm Transformation Bridge Rules: Prohibition Transformation Rule

$$\frac{RC : (RC\ \langle F, A, E, C, S, R \rangle, \delta_{nr})}{\begin{array}{c} NC : \lceil (B\ A, \delta_A) \wedge (B \neg E, \delta_E) \wedge (D^- C, \delta_C) \wedge (D^- S, \delta_S) \wedge (D^+ R, \delta_R) \\ \rightarrow \\ (D^- C, f(f_{compliance}(\delta_C, \delta_S, \delta_R), f_{activation}(\delta_A, \delta_E, \delta_{nr})))\rceil \end{array}}$$

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Norm Transformation Bridge Rules: Norm Activation Function

The norm activation function combines the belief degrees related to the norm activation and expiration conditions (β_A and β_E) and the certainty degree of the norm (ρ_n):

$$f_{activation}(\beta_A, \beta_E, \rho_n) = \beta_A \times \beta_E \times \rho_n$$

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Norm Transformation Bridge Rules: Norm Compliance Function

The norm compliance function takes as input the positive/negative degrees of the norm condition (δ_C), the undesirability of sanction (δ_S) and the interest on the reward (δ_R):

$$f_{compliance}(\delta_C, \delta_S, \delta_R) = \delta_C \times \delta_S \times \delta_R$$

m-Water Case-Study: Norm Transformation

In the m-Water case-study, once the norm has been recognised by the RC it is transformed into an inference rule inside the NC (Bridge Rule 7):

$$\frac{RC : (RC\ \langle Prohibition, drought, -, fullIrrigation, payFine, -\rangle, 1)}{NC : \lceil (B\ drought, 0{,}6) \wedge (D^{-}\ payFine, 0{,}8) \rightarrow (D^{-}\ fullIrrigation, 0{,}48) \rceil}$$

$$f_{activation}(\delta_A, \delta_E, \delta_{nr}) = \delta_A \times \delta_E \times \delta_{nr} = 0{,}6$$

$$f_{compliance}(\delta_C, \delta_S, \delta_R) = \delta_C \times \delta_S \times \delta_R = 0{,}8$$

$$f(f_{activation}(\delta_A, \delta_E, \delta_{nr}), f_{compliance}(\delta_C, \delta_S, \delta_R)) = 0{,}6 \times 0{,}8 = 0{,}48$$

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Norm Internalization Bridge Rules: Updating Mental Context Rules

After performing the inference process for creating new desires ($\lceil (D^* \ \gamma, \delta) \rceil$), the NC must update the DC:

$$\frac{NC : \lceil (B \ \gamma, \delta) \rceil, \delta > \delta_{thres}}{B : (B \ \gamma, \delta)}$$

$$\frac{NC : \lceil (D^* \ \gamma, \delta) \rceil, \delta > \delta_{thres}}{D : (D^* \gamma, \delta)}$$

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m-Water Case-Study: Norm Internalization

In the m-Water scenario, the inferred normative desire is inserted into the DC (Bridge Rule 9), being $\delta_{threshold} = 0{,}4$:

$$\frac{NC : \lceil (D^{-} fullIrrigation, 0{,}48) \rceil \wedge 0{,}48 > 0{,}3}{DC : (D^{-} fullIrrigation, 0{,}48)}$$

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m-Water Case-Study: Norm Decision Making

The IC is updated creating a new intention whose intentionality has been reduced :

$$\frac{DC : (D^{+} [fullIrrigation] highQuality, 0{,}75), DC : (D^{-} fullIrrigation, 0{,}48), \quad PC : plan(fullIrrigation), 0{,}75 > 0{,}48}{IC : (I[fullIrrigation] highQuality, 0{,}27)}$$

Finally, the intention update implies the modification of the agent behaviour:

$$\frac{IC : (I[halfIrrigation] highQuality, 0{,}6)}{CC : (act(halfIrrigation)}$$

Thus, the agent fulfils the norms and changes its irrigation policy

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Experiment Description I

Irrigator communities are formed by agents:

- Each agent needs a fixed daily *need of water* along its *cultivation period*
- There is a total amount of *available water*
- The *needs of water*, *cultivation periods* and *available water* are assigned randomly in each simulation
- In each iteration (i.e. each day), agents should decide their irrigation policy:
    - To irrigate all their cultivation
    - To irrigate a half of their cultivation

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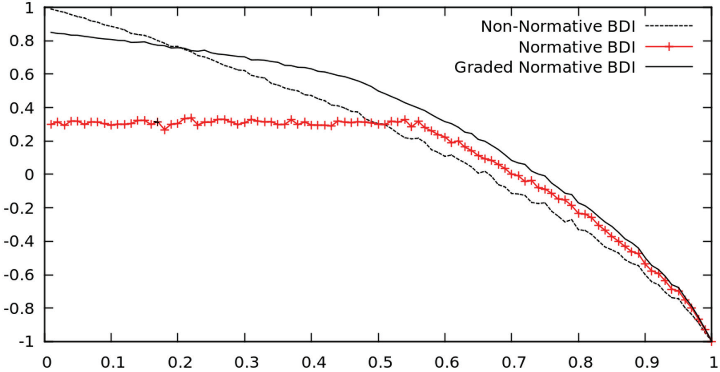
Experiment Description II

Irrigator communities are formed by agents with are:

- *Classic BDI agents*, which are non-normative and they always irrigate all their cultivation if there is enough water
- *Normative* agents, which always irrigate a half of their plantation since there is a drought situation
- *Graded Normative* agents which consider how restrictive the situation is; i.e. they decide to irrigate a half of their cultivation if there is a serious drought (the amount of required water is more than twice the available amount).

Results



Average agent satisfaction S (vertical axis) with respect to the seriousness of the drought situation Se (horizontal axis)

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Contributions

Normative Graded BDI architecture:

- Allows the **acquisition** of new norms from their environment and consider them in decisions
- Allow agents to represent **uncertain** knowledge about the current state of the world
- The desirability degrees of desires and intentions allow agents to **decide** between norm violation or fulfillment according to their priorities

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Future Work

- The impact of normative decisions on agent cognitions will be object of future work:
  - *Deliberative coherence*
    - Deals with goal adoption in the context of decision making, will be considered when building plans for obeying or violating norms
  - *Emotions*
    - Consider phenomena such as shame, honour, gratitude, etc. in their decision making processes
- Implementation of a prototype of the n-BDI architecture
  - Evaluate empirically our proposal
  - Scenarios belonging to the m-Water case study

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